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SPICE-Oriented Stability Assessment Using Limited Number of Variables

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1. Introduction

The assessment of the stability is very important for designing the circuit. In this article, we propose a SPICE-oriented method for the assessment of the stability, which is based on the Floquet theory. We have to choose all of variables in the conventional method. If the circuit has too many variables, it is difficult to assess the stability. We choose the variables from the necessary minimum variables. By combining our method with the conventional spice-oriented frequency analysis, we can assess the stability of the solution easily with SPICE. First, we obtain the periodic solutions of the circuit by using the SPICE. Next, we calculate the eigenvalues of an elementary matrix by solving variational circuits based on the Floquet theory. As an example, we assess the stability of the periodic solutions for a fifth order resonance circuit.

2. Stability of periodic solutions

We suppose that there is a circuit equation as

$$f(\dot{x},\ x,\ y,\ \omega t) = 0, \tag{1}$$

and make the variational equation for the regular period solution of $\hat{x}$. If we assume the small change quantity as $(\Delta x, \Delta y)$, we obtain the equation as

$$f(\dot{\hat{x}},\ \hat{x},\ \hat{y},\ \omega t) + \left[\frac{\partial f}{\partial \dot{x}}\frac{\partial f}{\partial x}\frac{\partial f}{\partial y}\right]|_{x=\hat{x},y=\hat{y}} \left[\begin{array}{c} \dot{\Delta x} \\ \Delta x \\ \Delta y \end{array}\right] = 0. \tag{2}$$

In Eq. (2), the first term is regular period solution and second term is variational equation. We change the second term as

$$\dot{\Delta x} = A(t)\Delta x. \tag{3}$$

In Eq. (3), $A(t)$ is the periodic function. We apply the Floquet theory for this periodic function. We write the elementary matrix of the periodic solution as $\Phi(t)$. From this, the solution after one period from initial value of $\Delta x(0)$ is given as follows;

$$\Delta x(T) = \Phi(T)\Delta x(0). \tag{4}$$

Hence, when the eigenvalues $(\lambda_1, \lambda_2, \ldots, \lambda_n)$ of $\Phi(T)$ satisfy $|\lambda_k| < 1$ $(k = 1, 2, \ldots, n)$, the regular periodic solution $\hat{x}$ is stable.

First, we develop the variational circuit from original circuit. We perform the transient analysis of the variational circuit for one period T, with different initial conditions. In this study, we choose a small number of variables compared with the conventional method.

3. Illustrative example and result

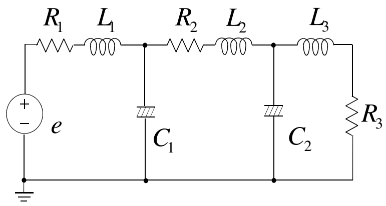

Figure 1: Example model.

We assess the stability of the solutions in Fig. 1 with 3 variables. In Fig. 1, we assume a sinusoidal voltage source and third order nonlinear characteristics for the capacitors as follows:

$$\begin{cases} e = E_m \sin \omega t \\ C_1\ ;\ v_1 = \alpha_1 q_1 + \beta_1 {q_1}^3 \\ C_2\ ;\ v_2 = \alpha_1 q_2 + \beta_2 {q_2}^3 \end{cases} \tag{5}$$

We set the parameters as follows; $E_m = 0.35[V], \alpha_1 = 2.4, \beta_1 = 12.0, \alpha_2 = 1.0, \beta_2 = 5.0, R_1 = 0.1[\Omega], R_2 = R_3 = 0.02[\Omega], L_1 = 0.2[H], L_2 = 0.8[H], L_3 = 0.10101[H]$. We assess the point of $\omega = 5.00[rad/s]$, which is in unstable region.

First, we show the results when we choose 5 variables in Table 1, namely the elementary matrix solution has 25 components. Next, we show the results when we choose only 3 variables in Table 1, namely the elementary matrix solution has 9 components.

Table 1: Eigenvalues of Φ.

	$\lvert\lambda_1\rvert$	$\lvert\lambda_2\rvert$	$\lvert\lambda_3\rvert$	$\lvert\lambda_4\rvert$	$\lvert\lambda_5\rvert$
$(i_1, i_2, i_3, q_1, q_2)$	0.53	0.53	0.41	0.85	1.04
(i_1, i_2, i_3)	0.35	0.85	1.62	-	-
(i_2, i_3, q_1)	1.50	0.60	0.46	-	-
(i_1, i_3, q_2)	0.45	0.26	1.20	-	-

From the Table 1, we succeed the assessment of stability with small number of variables. If we choose 2 variables, namely the elementary matrix solution has 4 components, wrong results are obtained.

4. Conclusions

We proposed SPICE-oriented method for the assessment of the stability, which is based on the Floquet theory. We succeed the assessment of stability with small number of variables. As a future work, we would like to apply our proposed method to circuits with more variables.

References

[1] Donald O. Pederson and Kartikeya Mayaram: *Analog Integrated Circuits for Communication*, Kluwer Academic Publishers, 1991.